3J3-1

9 GHz Harmonic Surface Acoustic Wave Resonator with Grooved Al Electrodes in $LiNbO_3$

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1. Introduction

Bulk acoustic wave (BAW) and surface acoustic wave (SAW) filters are key components in mobile phones.[1) 2)] Currently, these acoustic wave filters are expected to cover a high-frequency range of 7–24 GHz for Frequency Range 3 (FR3), as allocated by 3GPP. However, there are no suitable acoustic wave filter that can adequately cover this range. BAW and SAW devices work high frequency by thinning the piezoelectric film and shortening the wavelength (λ) of the interdigital transducer (IDT), respectively. However, these approaches have limitations due to power handling and mechanical strength issues in mobile phones, making them impractical for real-world applications. The IDT λ of SAW filters must be 1.2 μm or longer, which limits the upper frequency of the standard SAW filter to 3.2 GHz.[3)]

Simulation by finite element method (FEM) (FEMTET: Murata Software) revealed that embedding IDT in $LiNbO_3$ (LN) or $LiTaO_3$ (LT) excites harmonic SAWs.[4)] Based on this result, we fabricated grooved Al IDTs with λ below 1.2 μm in 26°YX LN, successfully exciting an 8 GHz harmonic SAW, which is 2.4 times higher in frequency than the fundamental mode.[4)] In this paper, we further report on the excitation of a 9 GHz harmonic SAW.

2. Simulation

Standard SAW devices with an IDT metallization ratio (MR) of 0.5 on LN and LT typically excite only the fundamental mode.[4)] Fig. 1 shows simulated frequency responses of four types of SAW resonators on 26°YX LN with an IDT λ of 1.2 μm and a MR of 0.5. Type (a) assumes a conventional Al IDT of 0.08λ thickness on LN. Types (b), (c) and (d) assume grooved Al IDT with depths of 0.08λ, 0.28λ, and 0.34λ in LN, respectively. The mechanical loss ($1/Q_m$) of LN is assumed as 1/200, and no loss is cosidered for the Al electrode.

For type (a), only the fundamental mode at the center frequency (f_c) of 3.62 GHz is observed. For types (b), (c), and (d), on the other hand, the third harmonic SAW is clearly visible. The depth of the grooves is an important parameter to optimize. A sharrow grooved IDT in (b) excites the third harmonic SAW weakly. A deeper grooved IDT is better for the excitation of the third harmonic SAW, but a spurious response in the high frequency side is also excited and f_c decreases due to mass loading as found in (c) and (d).

Fig. 2 shows the dependence of bandwidth (BW) and impedance (Z) ratio on the second Euler angle θ of (0°, θ, 0°) LN. A MR of 0.5, an IDT λ of 1.2 μm, and a depth of the grooved Al electrode of 0.3 λ are assumed. The BW is larger than 6.3% when θ = 110°–138°, and the Z ratio is higher than 68 dB when θ = 103°–122°. Considering these results, θ of 116° was selected.

Fig. 3 shows anti-resonant velocity and Z ratio of the fundamental and third harmonic modes as a function of the depth of an Al grooved electrode in 26°YX LN, where an MR of 0.5 and an IDT λ of 1.2 μm are assumed. The velocity of the fundamental mode remains constant regardless of the groove depth. In contrast, the velocity of the third harmonic mode decreases as the groove depth increases, as mentioned above. The highest Z ratio of the

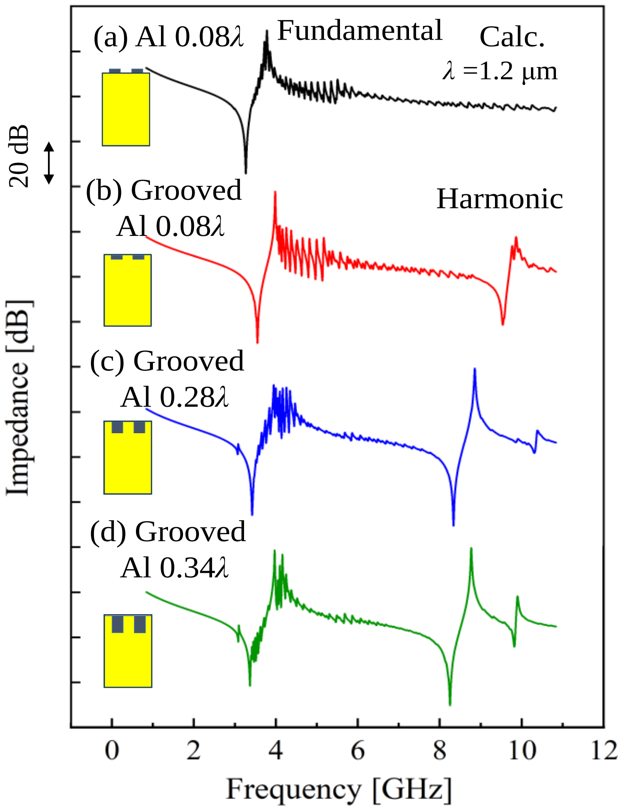

Fig. 1 Simulated frequency responses of (a) 0.08λ thick Al IDT on 26°YX LN, (b) 0.08λ deep grooved Al IDT in LN, (c) 0.28λ deep grooved Al IDT in LN, (d) 0.34λ deep grooved Al IDT in LN (MR is 0.5 and IDT λ is 1.2 μm).

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fundamental and harmonic modes is obtained around 0.15λ and 0.34λ, respectively.

3. Fabrication

A 0.25 mm thick 26ºYX black LN was used. The grooves were fabricated by dry etching. Al was deposited to fill the grooves, and the substrate surface was finished by CMP.[5] Fig. 4 shows the frequency characteristic of the SAW resonator with an IDT λ of 1.2 μm. The excited harmonic SAW exhibits a resonance frequency (f_r) of 8.5 GHz, an anti-resonance frequency (f_a) of 9.1 GHz, a BW of 7.6%, and an Z ratio of 34 dB. The frequency is 2.4 times as high as that of the fundamental mode.

The resonator consists of two divided IDTs with 59.5 pairs in total and an aperture of 20λ, and grating reflectors with 35 fingers at each side of the IDT. The MRs of the surface and bottom of the groove IDT are about 0.6 and 0.2, respectively, because the groove is tapered. The slope of the groove walls is 65–70º. Simulation suggests that the

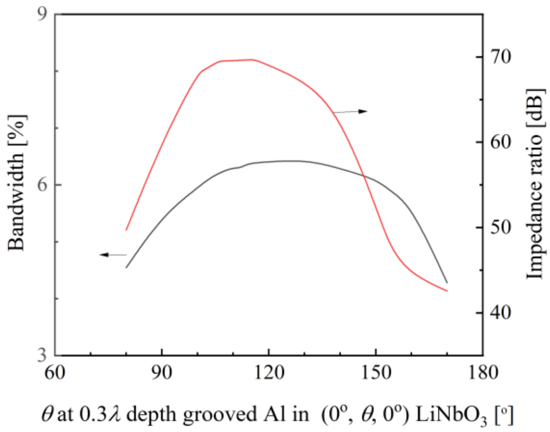

Fig. 2 BW (black line) and Z ratio (red line) on the second Euler angle θ of (0º, θ, 0º) LN (MR = 0.5, IDT λ of 1.2 μm, and depth of 0.3λ).

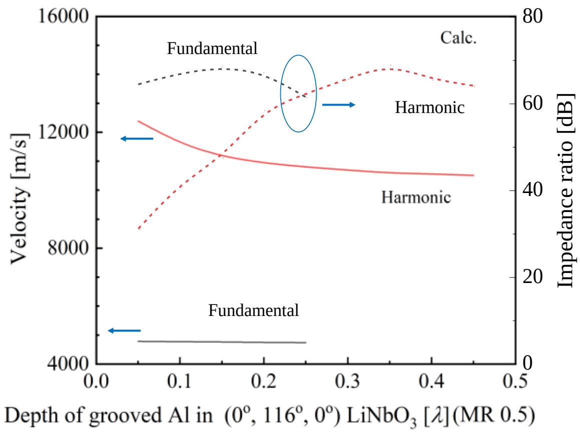

Fig. 3 Anti-resonant velocity and Z ratio of fundamental and harmonic modes as function of grooved Al IDT depth in 26ºYX LN (MR is 0.5 and IDT λ is 1.2 μm).

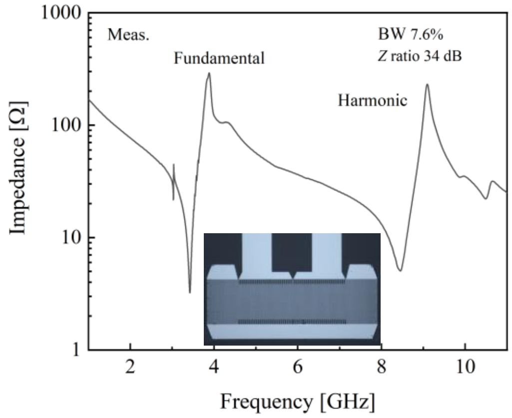

Fig. 4 Measured frequency characteristic of SAW resonator with about 0.26λ deep grooved Al IDT in 26ºYX LN (Average MR is 0.4 and IDT λ is 1.2 μm).

slope closer to 90º is better, but 65–70º is already a good result to practically achieve.[4] We expect a better frequency response by better filling the grooves with Al, increasing the average MR, which is 0.4 at present, and further optimizing the device design.

4. Conclusion

FEM simulation revealed that SAW resonator with grooved IDT in LN strongly excites the third harmonic SAW, and that 26ºYX LN is an optimal rotated angle for achieving wide BW and high Z ratio. We fabricated a SAW resonator with grooved Al IDT with λ of 1.2 μm in 26ºYX LN. The fabricated SAW resonator excited the third harmonic SAW at f_a of 9.1 GHz, exhibiting a BW of 7.6% and an Z ratio of 34 dB. The grooves, which have a narrow average MR of 0.4, a shallow depth of about 0.26λ, and a sidewall angle of 65–70º, significantly impact the device characteristics. Improving the fabrication process, particularly in metal filling, is crucial for enhancing the device design.

Acknowledgment

This research was partly supported by SCOPE #JP225002001. We thank SHINCRON Co., Ltd. and NIHON DEMPA KOGYO Co., Ltd. for their technical supports.

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